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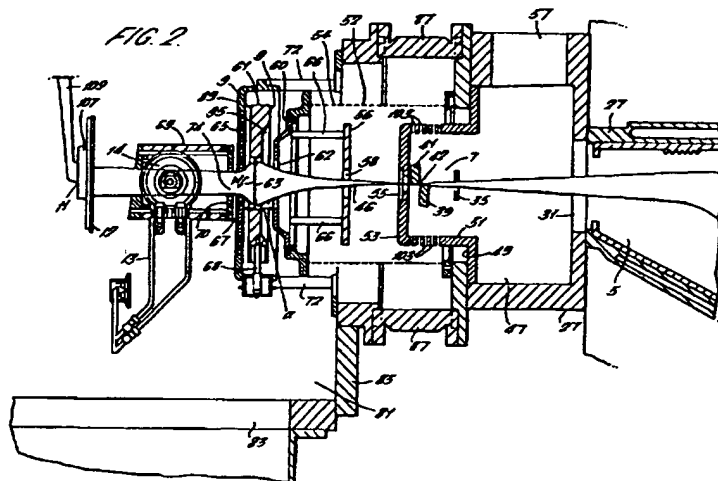　　Jonathan Gerald England
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(54) Abstract Title
　　An Ion Implanter with three electrode deceleration structure and upstream mass selection

(57)　An ion implanter has a deceleration lens assembly 9 located between a flight tube 5 for transporting a b am of ions at a transport energy and a substrate holder 11. The assembly comprises a first apertured plate lectrode 65 connected to be substantially at the substrate potential with a field electrode 61 located adjacent and upstream in the beam direction. The field electrode 61 is biased relative to the first electrode 65, to provide a focusing field for beam ions passing through said first electrode 65. The assembly further includes a second apertured plate electrode 60 located adjacent and upstream in the beam direction. The implanter also comprises mass selection apparatus in the flight tube to select a desired mass of ions for transmission in the ion beam from the flight tube, the apparatus including an electromagnetic screen 53 to screen the mass selection apparatus from electric fields generated downstream and providing an exit aperture 55 for the mass selected ion beam from the flight tube, and at least one additional mass selection apparatus screening lectrode 56 the flight tube potential located between the second electrode 60 and the exit aperture 55. A scr ening cylinder 54 may also be provided, the second electrode 60 being mounted at one end of the cylinder and the electrode 56 being mounted within it.
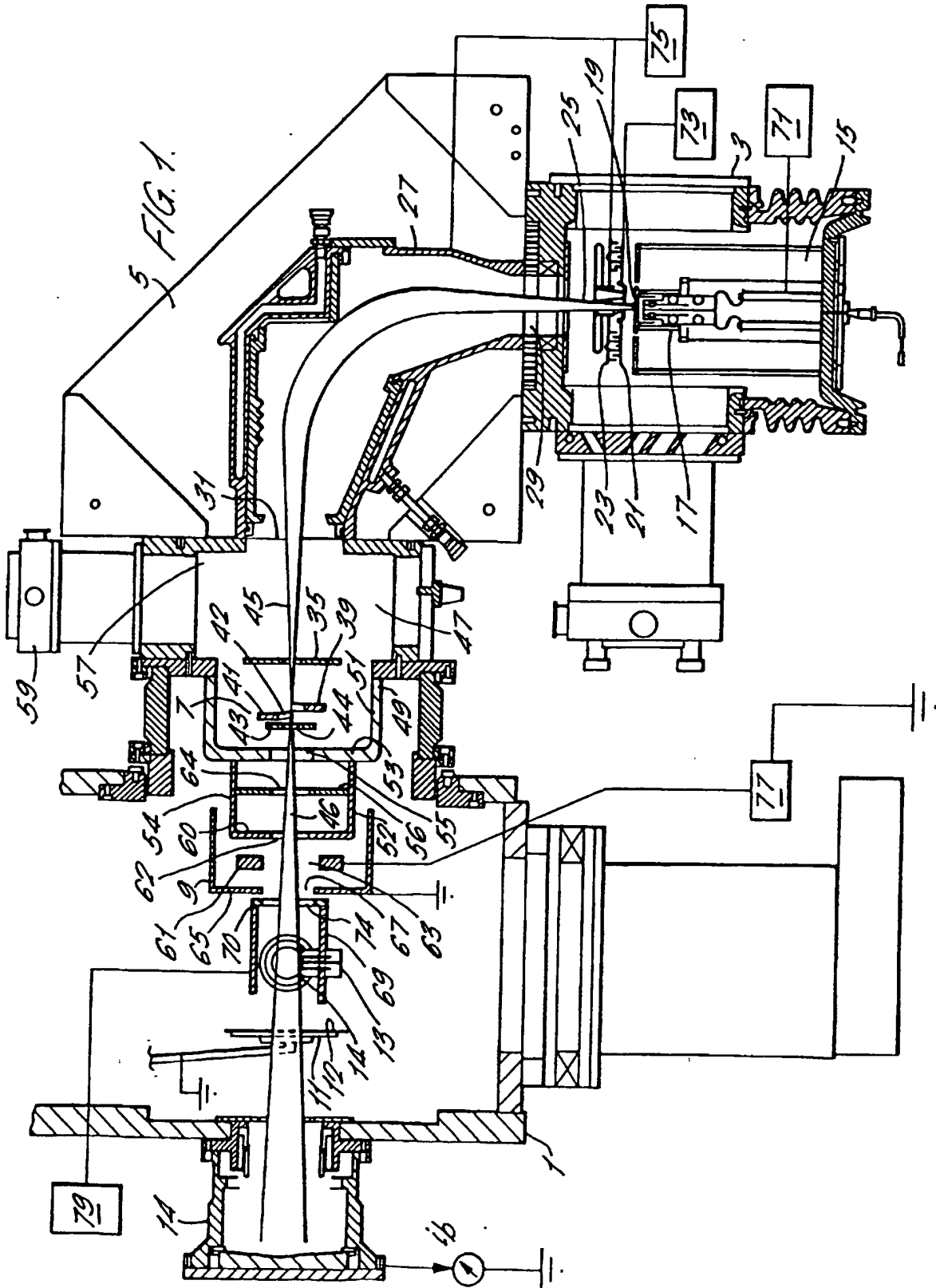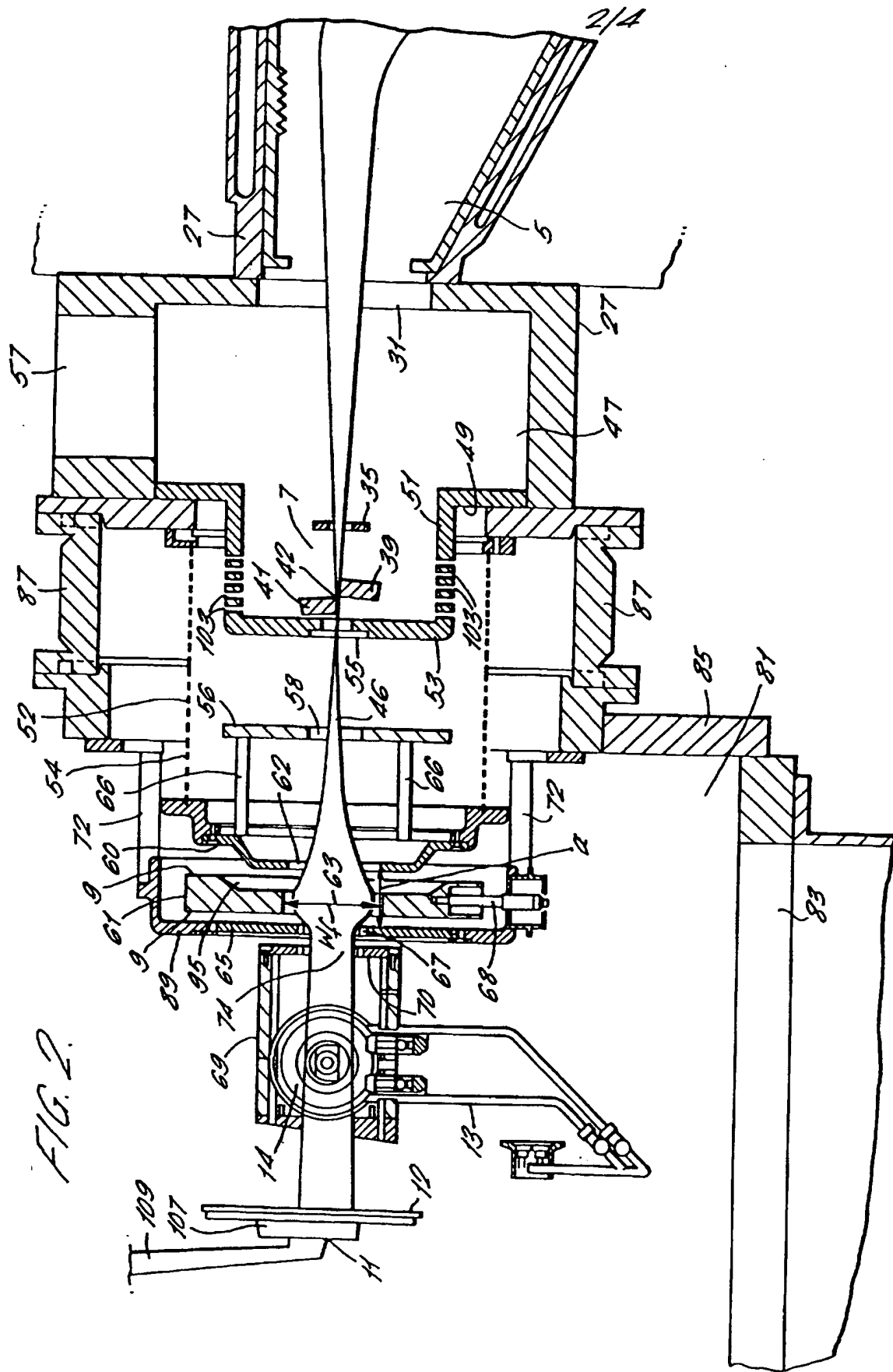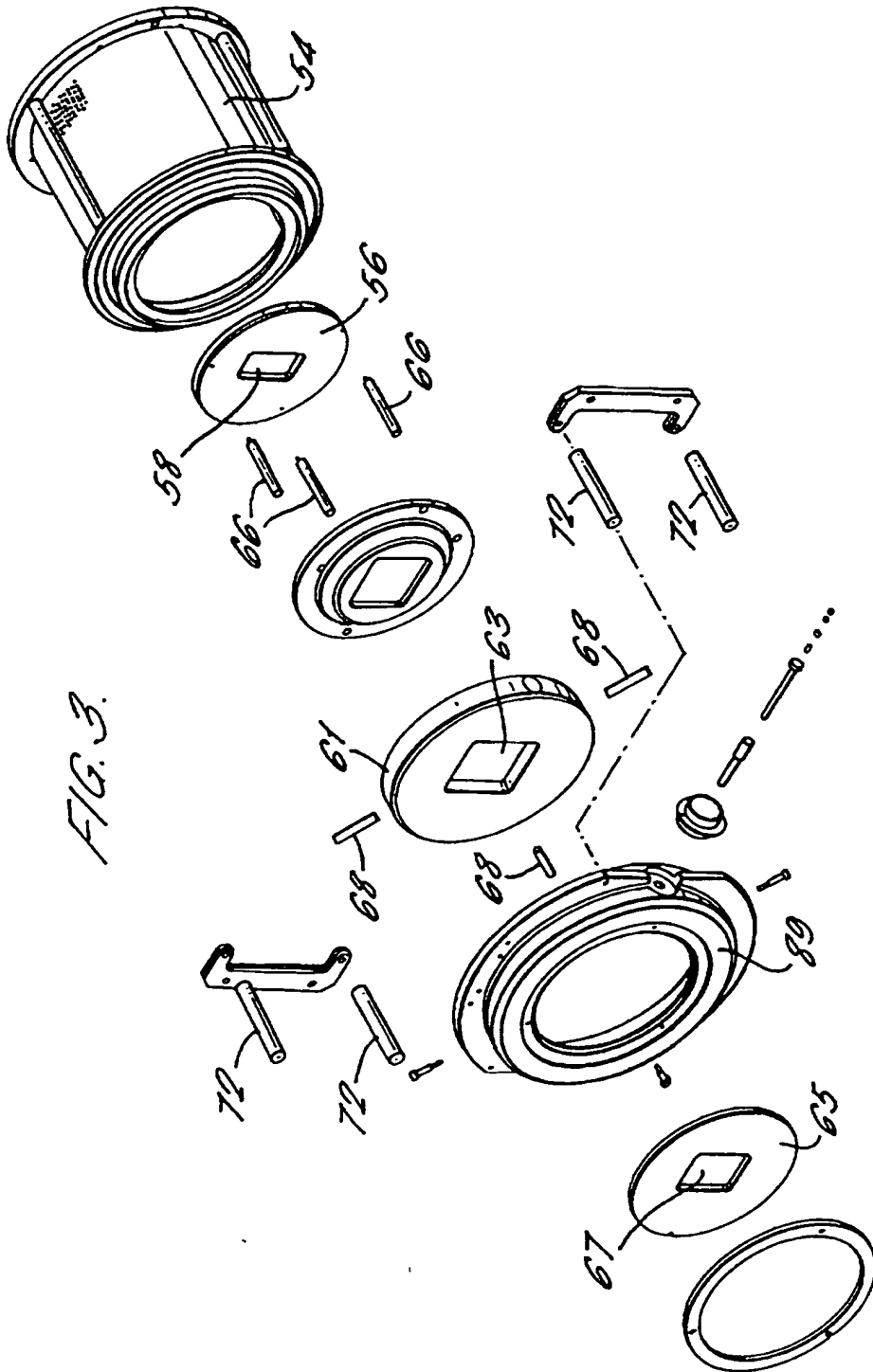
FIG. 2

1/4

5 FIG.1

FIG. 2

FIG. 3.

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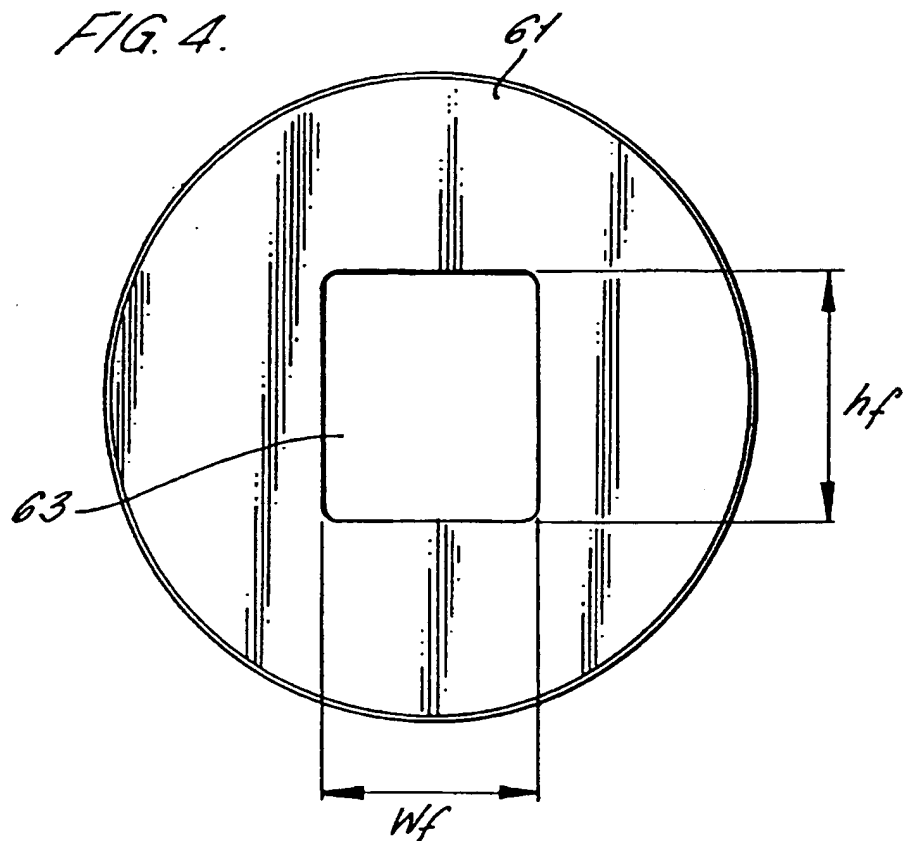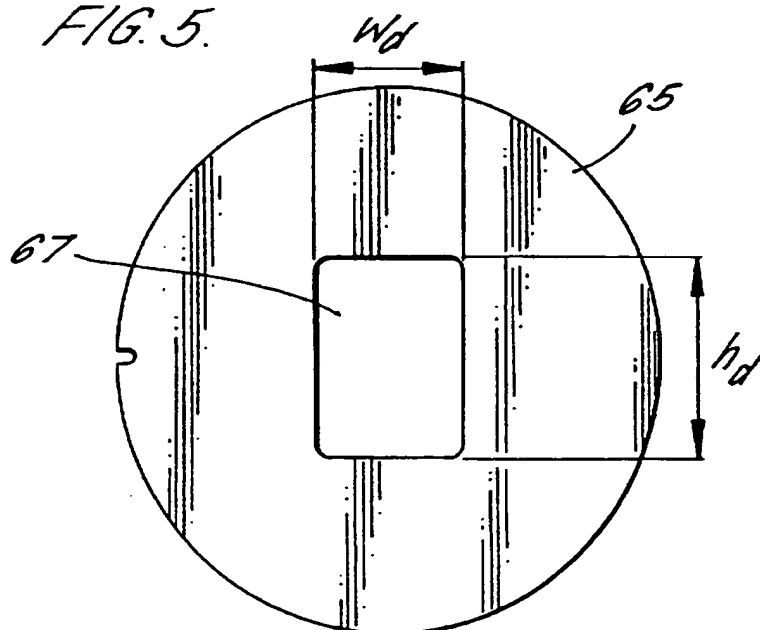67

65

FIG. 4.

61

63

hf

Wf

FIG. 5.

Wd

65

67

hd

TITLE OF INVENTION

AN ION IMPLANTER WITH THREE ELECTRODE
DECELERATION STRUCTURE AND UPSTREAM MASS SELECTION

FIELD OF THE INVENTION

This invention relates to ion implanters for implanting ions into substrates, such as semiconductor wafers, in electronic device fabrication, and in particular to ion implanters capable of processing wafers on a commercial scale with relatively low implant energies.

DESCRIPTION OF THE PRIOR ART

Ion implantation techniques are commonly used as one of the processes employed in the manufacture of integrated circuits, to modify the electrical transport properties in predefined regions of a semiconductor material by doping these regions with a predetermined concentration of impurity atoms. The technique generally involves generating a beam of a preselected specie of ions and directing the beam towards a target substrate. The depth of the ion implant depends, inter alia, on the energy of the ion beam at the substrate. As the density of devices on a single wafer increases and the lateral dimensions of individual devices decrease for ultra-large scale integrated circuits (ULSI), the ability of an ion implanter to form shallow junctions using low energy ions, e.g. of about 2 keV to 10 keV, becomes

increasingly important. At the same time, in
commercial ion implantation, it is also important to
be able to process an individual wafer in as short a
time as possible and this requires the ion beam
5   current to be as large as possible. Unfortunately,
the requirement of a low energy beam tends to conflict
with the requirement of a high current beam, since it
is extremely difficult to transport an ion beam at low
energy and high current due to space charge effects.
10   A known scheme to avoid the problem of beam
expansion and loss of beam current is to transport the
ion beam at high energy and then decelerate the beam
to the desired low energy just before the beam impacts
the substrate. For example, Applied Physics Letters
15   53 (18) 31st October, 1988, pages 1741 to 1743,
S.N. Hong et al describes a conventional ion implanter
which has been modified in order to study implant
depth profiles by incorporating into the implant
chamber a decelerating lens system in which a fixed
20   target substrate is held. A retarding power supply is
connected between the retarding lens and the beam
extraction power supply such that the final energy of
the ions just prior to impacting the target is
determined solely by the retarding potential generated
25   by the retarding power supply. Ions are extracted
from the ion source at an energy of 35 keV and are
passed through an analyser magnet which analyses the
ions transported in the beam according to their mass.
The mass analysed beam is then passed to an X-Y
30   scanner which deflects the beam from the path between
the magnet and the scanner along another path directed
at the target. The retarding lens and target, which
are biased at 34 kV, decelerate the beam from 35 keV

to the fixed implant energy of 1 keV. Thus, ions are transported at high energy along the path between the ion source and the implant chamber to minimize beam expansion due to space charge effects and

5   consequential loss of current. The energy of the ion beam is then only reduced just in front of the target, before impact, so that the beam travels a very short distance at low energy, again to minimize beam expansion.

10   One problem with the method of transporting the ion beam at relatively high energy and then decelerating the ion beam very close to the target is that, along the passage of the high energy beam, a proportion of the beam ions are neutralized through

15   charge exchange processes with residual gas atoms and become high energy neutrals which, if directed at the target, will pass through the retarding lens without being slowed. These high energy neutrals penetrate more deeply into the substrate than the low energy

20   ions, which is particularly undesirable when forming shallow junctions. The effect of these high energy neutrals on the implant depth can be seen as a high energy tail in the depth profile as measured by secondary ion mass spectroscopy (SIMS).

25   Review of Scientific Instruments 65(8) August 1994, pages 2680 to 2692, A. H. Al-Bayati et al describes a mass analysed, low energy, dual ion beam system for materials research. The apparatus comprises a pair of Freeman sources each with

30   associated extraction electrodes, an analysing magnet for mass analysing the ion beam, a further magnet for focusing the beam, electrostatic deflectors for scanning and gating the ion beam, an ultra-high vacuum

(UHV) deposition chamber housing a retarding lens for reducing the energy of the ion beam and a target mounted within the lens. The apparatus is designed to allow materials to be deposited as well as implanted

5   into the substrate and the ion arrival energy can be controlled from 5 eV to 10 keV. The dual ion source together with the mass analysing magnet allow alternate layers of different materials to be deposited. The ultra-high vacuum deposition chamber

10   houses equipment for in-situ Auger electron spectroscopy and reflection high-energy electron diffraction analysis of the deposited material. A second UHV chamber, connected to the deposition chamber by means of a vacuum lock and sample transfer

15   device, houses equipment for in-situ low energy electron diffraction and time of flight scattering and recoiling spectrometry. The deposition chamber is maintained at ultra-high vacuum in order to minimize contamination of the target surface during the

20   deposition processes. After the beam has been mass-analysed, the second magnet refocuses the beam to a point several centimetres in front of the target. The ion beam is transported at an energy of 10 keV into the deposition chamber, where the energy of the beam

25   is reduced to the desired value by the retardation lens. Thus, a proportion of the beam ions will be converted into 10 keV neutrals by charge exchange processes as the beam travels to the target. The number of neutrals which actually reach the target is

30   reduced by the second magnet, which bends the ion beam off the beam trajectory from the first magnet so that neutrals generated between the first and second magnets do not reach the target. Neutral production

is further reduced by maintaining the deposition
chamber under ultra-high vacuum so that neutral
production along the straight path between the second
magnet and the target is minimal.

5   The retardation lens is configured as a cup with
part of the lens being parallel to the beam axis and
an end part normal to the beam axis in which the
target is mounted. In practice, the retardation lens
and target are maintained at ground potential and the
10   flight tube is biased negatively with respect to
ground. A further electrode is positioned at the
entrance of the retardation lens and is slightly
negatively biased with respect to the flight tube in
order to prevent the retardation field extending back
15   along the flight tube which would otherwise accelerate
electrons into the retardation lens thereby causing
loss of beam neutralization and a concomitant increase
in the rate of beam divergence in the flight tube.
The entrance aperture of the suppression electrode and
20   the diameter of the cup electrode are both
substantially larger than the beam diameter.

       The maximum on-target ion current density
achievable in this instrument is about 100 μAcm^{-2},
although the reported current densities are
25   substantially lower. As the target chamber is
maintained under UHV conditions, e.g. at pressures
from 10^{-4} – 10^{-8} Pa (10^{-6} to 10^{-10} mbar), and the sources
operate at pressures of 1 Pa (10^{-2} mbar), differential
pumping stages along the beam line are required, which
30   increases the length of the beam line to almost 4 m.
Further, there are no provisions for neutralising
surface charge build-up as required for higher current
implantation of semiconducting substrates.

Nuclear Instruments and Methods in Physics
Research, B74 (1993), pages 160 to 169, D. F. Downey
et al describes various methods of characterising an
ion implanter's performance when implanting ions at
5   low energy. As in the above references, the ion beam
is initially transported at relatively high energy and
subsequently decelerated to the desired implant
energy. The particular implanters used each had a
multi-electrode acceleration tube which was used to
10   decelerate the ion beam in a stepped manner, so that
the deceleration voltage was distributed over the
length of the acceleration tube, rather than
decelerating the beam to the required energy just in
front of the target. Gradual deceleration of the ion
15   beam along the acceleration tube is reported to
improve beam transport by minimizing focusing effects
of the tube, thereby optimizing the beam current.
Such an arrangement is also reported to minimize
neutral formation. In one investigation, the implant
20   depth profile is studied as a function of beam
extraction voltage to determine the extent to which
neutrals affect the depth profile, for sets of ion
implant energies of between 3 and 10 keV. A neutral
peak was readily observed in the depth profile for the
25   higher extraction voltages, indicating that neutral
contamination is an important factor when determining
the energy at which the ion beam should be transported
before being decelerated to the required energy. The
maximum achievable beam current for a 5 keV boron
30   implant was of the order of 1 mA.

An object of the present invention is to provide
an improved ion implanter capable of implanting ions
at low energy and at beam current densitites which

enable semiconductor wafers to be processed on a commercial scale.

An ion implanter capable of operating at low implant energies and with substantial beam currents is disclosed in our co-pending application/filed on even *(GB Application No. 9616240.9)* date herewith and claiming priority from GB Application No. 9522883.9. In this arrangement a deceleration lens assembly is provided between the substrate holder and the flight tube through which the beam is transported at a transport energy normally above the desired implant energy. The deceleration lens assembly includes at least two, and normally three, electrodes with a first electrode held substantially at the substrate potential and an adjacent field electrode which is biased to be at a sufficient potential relative to the first electrode to produce a focusing field at the first electrode to counteract the tendency of beam ions to blow up under space charge effects whilst the beam is in the decelerating field. Typically, for positive beam ions, the field electrode is biased at a negative potential relative to the first electrode which is of sufficient magnitude so that the field electrode is also at a substantial negative potential relative to the flight tube potential. Thus, the field electrode also acts as an electron suppression electrode preventing electrons in the beam in the flight tube from being drawn out of the beam by the deceleration field. However, the potential on the field electrode is much greater (in the negative direction) than would be required merely for electron suppression purposes, so that the field electrode in combination with the first electrode at the substrate potential can provide

the necessary focusing effect.

In tests with a beam decelerating implanter of the kind described above, the inventors have found that there can be problems with high energy

5   contamination of the substrate, at energies above the transport energy of the beam through the flight tube. The inventors have discovered that this higher energy contamination results from beam ions being neutralised as they are temporarily accelerated by the field

10   electrode before being decelerated between the field electrode and the first electrode at the substrate potential. An object of embodiments of the present invention is to reduce this higher energy contamination to negligible levels.

15   According to one aspect of the present invention, there is provided an ion implanter for implanting ions into a substrate, comprising an ion beam generator for producing a beam of ions, a flight tube to transport said beam at a transport energy, a substrate holder

20   for holding a substrate to be implanted with beam ions, a deceleration potential generator connected to apply a deceleration potential between the flight tube and the substrate holder to decelerate beam ions to a desired implant energy, a deceleration lens assembly

25   located between the flight tube and the substrate holder and comprising a first apertured plate electrode connected to be substantially at the substrate potential, and a field electrode located adjacent and upstream in the beam direction relative

30   to said first electrode, a potential bias supply connected to bias said field electrode relative to said first electrode, said electrodes being arranged and said bias being such as to provide a focusing

field for beam ions passing through said first
electrode, said deceleration lens assembly further
including a second apertured plate electrode connected
to be substantially at the flight tube potential and
5   located adjacent and upstream in the beam direction
relative to said field electrode, mass selection
apparatus in the flight tube to select a desired mass
of ions for transmission in the ion beam from the
flight tube, said mass selection apparatus including
10   an electromagnetic screen at the flight tube potential
to screen the mass selection apparatus from electric
fields generated downstream in the beam direction,
said screen providing an exit aperture for said mass
selected ion beam from the flight tube, and at least
15   one additional mass selection apparatus screening
electrode comprising an apertured plate at the flight
tube potential located between said second electrode
and said exit aperture.

By keeping the distance in the beam direction
20   between the first and second apertured plate
electrodes to a small value, the time during which
beam ions are temporarily accelerated by the field
electrode to an energy above the transport energy
through the flight tube, is kept to a minimum. As a
25   result, the probability of beam ions at this higher
energy experiencing electron exchange collisions with
residual gas ions is reduced and the number of higher
energy neutrals formed in this region is also
substantially reduced. In the invention as described
30   above, beam ions are temporarily accelerated only in
the short distance between a point a little upstream
of the second electrode and the mid point of the field
electrode, whereafter the beam ions are decelerated

again. Because this distance is so short and the
residence time of beam ions in this region is also
short, high energy contamination is reduced.

The additional screening electrode prevents
fields from the field electrode, which may penetrate
through the aperture of said second electrode, from
extending significantly beyond the position of this
additional screening electrode. This allows the
distance between the field electrode and the mass
selection apparatus to be kept to a minimum without
electric fields penetrating the mass selection
apparatus and disturbing the mass selection process.
As a result, the flight time of beam ions at the
transport energy from the mass selection apparatus
towards the deceleration lens assembly is kept to a
minimum so that the possibility of neutral
contamination of the target at the transport energy is
reduced. Also, by preventing the acceleration field
produced by the field electrode from penetrating
upstream along the beam, neutralising electrons can
exist in the beam over a greater distance towards the
field electrode so that the tendency of the beam to
blow up through space charge effects is also reduced.

Preferably, the implanter includes a screening
cylinder mounted on the flight tube at the flight tube
potential and extending axially towards said field
electrode to contain the ion beam, said second
apertured plate electrode being mounted on the end of
the screening cylinder adjacent to the field electrode
and said screening cylinder being perforated to assist
evacuation of the interior of the cylinder. Then, the
apertured plate forming said additional screening
electrode can be located in said screening cylinder.

In a preferred embodiment, the implanter includes
neutralisation apparatus located between the substrate
holder and said first electrode to provide a supply of
low energy charged species of opposite polarity to the

5   beam ions for neutralising surface charge build-up on
the substrate during implantation. Then, the
implanter preferably includes a neutralisation
apparatus screening electrode comprising an apertured
plate located between said first electrode and said

10   neutralisation apparatus. In a preferred arrangement,
the neutralisation apparatus includes an electron
confinement tube surrounding the beam immediately in
front of the substrate holder, whereupon the
neutralisation apparatus screening electrode may be

15   mounted directly on the upstream end of this electron
confinement tube.

This construction is very important in permitting
the field electrode to be located as close as possible
to the substrate while still permitting the

20   neutralisation apparatus to be located between the
two. Because the neutralisation apparatus operates by
providing a flood of low energy charged species,
usually electrons for a positive ion beam, it is very
important to prevent extraneous electric fields from

25   penetrating into the neutralisation region. It has
been found that the presence of the additional
screening electrode permits the first electrode to be
located very close to the upstream end of the electron
confinement tube and for the confinement tube itself

30   to be made relatively short whilst still providing
adequate neutralisation of the substrate being
implanted.

Preferably, said first apertured plate electrode

has a cylindrical screening flange extending axially from the first electrode towards said field electrode and the field electrode is mounted inside the flange so that the flange surrounds the outer periphery of the field electrode. This construction minimises the tendency of electric field from the field electrode penetrating round the outside periphery of the first electrode towards the substrate holder and neutralisation apparatus.

In a further preferred embodiment, the implanter includes a process chamber containing said substrate holder and having an outlet port, and a vacuum pump connected to said outlet port for evacuating the process chamber, wherein said deceleration lens assembly is located directly in front of said outlet port to the vacuum pump. This is another feature which is very important in reducing neutral contamination at energies to which beam ions are temporarily accelerated as they pass the field electrode. By locating the deceleration lens assembly, where beam ions are temporarily accelerated, immediately in front of the outlet port to the vacuum pump, the residual gas pressure in this region of the deceleration lens assembly can be minimised, so that the probability of an electron exchange collision in this region is minimised.

An apertured plate electrode is an electrode comprising a plate extending transversely of the beam direction and containing an aperture for the beam, wherein the axial dimension (in the beam direction) of the aperture is insignificant compared to the smallest transverse dimension of the aperture.

BRIEF DESCRIPTION OF THE DRAWINGS

Examples of embodiments of the present invention will now be described with reference to the drawings in which:-

Figure 1 shows a plan view of an ion implanter according to an embodiment of the present invention;

Figure 2 shows a plan view of an ion implanter according to a preferred embodiment;

Figure 3 shows an exploded view of the deceleration lens assembly and lens screening apparatus of the embodiment shown in Figure 2;

Figure 4 shows a front view of the field electrode shown in Figures 2 and 3, and

Figure 5 shows a front view of the first apertured plate electrode shown in Figures 2 and 3.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figure 1, an ion implanter 1 comprises an ion beam generator 3 for generating a beam of ions, a magnet 5 adjacent the ion beam generator for resolving spatially the beam ions according to their mass, an ion selector 7 disposed adjacent the analysing magnet 5 for selecting a specie of ions to be implanted into a target substrate and for rejecting other ions in the spatially resolved beam from the magnet, an electrode assembly 9 disposed adjacent the ion selector 7 for controlling the final energy of the ion beam before implantation, a support or holder 11 spaced from the electrode assembly 9 for supporting a target substrate 12 to be implanted with beam ions and an electron generator 13 disposed

between the electrode assembly 9 and the substrate
support 11 for introducing electrons into the ion beam
near the target surface to neutralise the beam and
wafer surface. An ion beam collector 14 is positioned

5   downstream of the substrate support 11 which serves as
a beam stop and ion current detector for dosimetry
measurements.

In more detail, the ion beam generator 3
comprises an ion source 15 including an arc chamber 17

10   having an exit aperture 19 formed in the front face
thereof. A pair of extraction electrodes 21,23 are
spaced from the exit aperture 19 for extracting ions
from the arc chamber and forming an ion beam 25. The
extraction electrode 21 which is closest to the exit

15   aperture 19 of the arc chamber serves as a suppression
electrode to prevent electrons forward of the beam
generator from flowing to the arc chamber. A flight
tube 27 is positioned between two poles (only one
shown) of the mass analysing magnet 5 for receiving

20   the ion beam from the beam generator 3 and for
controlling the transport energy of the ion beam
during its passage between the poles of the magnet 5,
which is determined by the potential difference
between the flight tube 27 and the ion source 15. In

25   this particular embodiment, the magnetic field
strength of the analysing magnet and the energy of the
ion beam through the magnet are chosen so that ions
having an appropriate mass are deflected through
approximately 90° and the flight tube 27 is configured

30   accordingly, with the analysing magnet exit aperture
31 being approximately orthogonal to the magnet
entrance aperture 29. The ion selector 7 comprises a
series of discrete elements 35, 39, 41 and 43 which

are spaced apart along the beamline 45 and define a
series of apertures which, in combination, select ions
of the correct mass to be implanted in the target
substrate while rejecting other spatially resolved
ions which pass through the analysing magnet 5. In
this particular embodiment, the ion selector 7
comprises a plate electrode 35 which rejects most of
the unwanted ion species exiting from the magnet, a
pair of elements 39, 41, which together define a
variable width mass resolving slit which passes only
the selected ion specie, and a further element 43
which defines the height of the ion beam. However,
the number of mass resolving elements and their
configuration may be varied.

The ion selector assembly is housed in a chamber
47 which forms part of the flight tube 27 and which is
disposed between the magnet and the electrode assembly
9. The flight tube 27 including the mass resolving
chamber 47 provides the means by which the beam is
transported from the ion beam generator to the
electrode assembly 9. The mass resolving chamber wall
49 comprises a part 51 which extends in the direction
of the beamline and defines a generally cylindrical
envelope, and a transverse part 53 adjacent the
cylindrical part 51 which constitutes a plate
electrode disposed transverse to the beam line and
defines an aperture 55 through which the beam can
pass, the aperture 55 being adjacent the final element
43 of the ion selector 7. The transverse part 53
provides an electromagnetic screen for screening the
ion selector 7 from electric fields originating
downstream of the ion selector, as will be described
in more detail below.

In this particular embodiment, a vacuum port 57
is formed in the chamber wall 49 near the analysing
magnet 5 which is connected to a vacuum pump 59 for
evacuating the chamber 47, although in another
embodiment this vacuum port may be omitted.

A screening assembly 52 is positioned between the
exit aperture 55 of the mass resolving chamber 47 and
the electrode assembly 9 to reduce penetration of the
electric field from the electrode assembly 9 into the
mass resolving chamber 47 through the exit aperture
55. The screening assembly 52 comprises a cylindrical
electrode 54, and a field defining electrode 56. The
cylindrical electrode 54 is arranged coaxially with
the exit aperture 55 of the mass resolving chamber and
with one end 58 positioned adjacent and connected to
the transverse part (or front end) 53 of the mass
resolving chamber wall 49. The cylindrical electrode
54 extends forward of the mass resolving chamber 47
and may have an inwardly extending radial flange 60
formed near or at the other end of the cylindrical
electrode 54 to provide additional screening, and
defining an exit aperture 62.

The field defining electrode 56, which may or may
not be used, comprises a circular plate with an
aperture 64 formed in the centre thereof. The field
defining electrode 56 is mounted within and supported
by the cylindrical electrode 54 and is positioned
about midway between the ends of the cylindrical
electrode 54 (although this may vary) and transverse
to beam line 45. The aperture 64 is preferably
rectangular or square and, in one embodiment may taper
gently outwards towards the electrode assembly 9. In
this example, the aperture is square and has a width

of about 60 mm. The cylindrical electrode 54 and the field defining electrode 56 may each be made of graphite or other suitable material.

The electrode assembly 9 for controlling the implant energy of the ion beam is situated just beyond the screening assembly 52, and comprises a field or ring electrode 61 and an apertured plate electrode 65. The field electrode 61, has a generally circular symmetry and defines an aperture 63 adjacent and substantially coaxial with the exit aperture 64 of the screening assembly 52. The plate electrode 65 is disposed generally transverse to the beamline 45 and defines a further aperture 67 through which the ion beam can pass, this further aperture 67 being disposed adjacent the field electrode aperture 63. The diameter of the field electrode and plate electrode apertures are about 90 mm and 80 mm, respectively, in this example. The field electrode and the plate electrode may each be made of graphite or other suitable material.

In this embodiment, the electron injector 13 comprises a plasma flood system which introduces low energy electrons into the ion beam near the target. The plasma flood system includes a guide or confinement tube 69 through which the ion beam can pass from the plate electrode aperture 67 to the target substrate 12, and which both maintains electrons from the plasma flood system in the vicinity of the ion beam and screens the portion of the ion beam between the plate electrode aperture and the wafer from stray electric fields. An apertured plate electrode 70 is positioned at the upstream end of the confinement tube, adjacent the apertured plate

electrode of the deceleration assembly to provide additional screening of the interior of the confinement tube from electric fields from the field electrode 61.

5   The apertures 63 and 67 formed in the field electrode 61 and the plate electrode 65 are each made larger than the beam cross-sectional area at these apertures, so that the ion beam can pass straight through without clipping the electrodes 61, 65. For a
10   given mass of ion and distance between each of these apertures 63,67 and the analysing magnet 5, the beam cross-sectional area will depend on such factors as the ion beam generator and magnet optics, the resolving power of the magnet and the width of the
15   mass resolving slit, each of which can be used to control the beam cross-sectional area at the retardation apparatus and the target substrate.

In this embodiment, the ion implanter further comprises an ion source voltage supply 71 for biasing
20   the ion source, a suppression electrode voltage supply 73 for biasing the suppression electrode 21, a flight tube voltage supply 75 for biasing the flight tube 27, the mass resolving chamber 47, the screening assembly 52, and the other extraction electrode 23, a field
25   electrode voltage supply 77 for biasing the field electrode 61 of the electrode assembly 9, and a plasma flood voltage supply 79 for biasing the electron confining electrode 69 and the apertured screening plate electrode 70. In this embodiment, the apertured
30   plate electrode 65 of the deceleration lens, the target substrate holder 11 and the substrate 12 are maintained at ground potential, which facilitates handling of the target substrate, simplifies the

target support assembly, and serves as a convenient reference potential for the other electrodes.

A method of operating the ion implanter to implant ions at low energy will now be described with
5 reference to a specific example for illustrative purposes only.

The ion implantation energy is determined by the potential difference between the substrate 12 and the ion source 15. As the substrate is maintained at
10 ground potential, the ion source voltage supply 71 is biased positively with respect to ground by an amount which corresponds to the desired ion implantation energy. For example, for a 2 keV implant, the ion source voltage supply is biased to +2 kV. The
15 transport energy of the ion beam through the analysing magnet 5 and the mass resolving chamber 47, which is also referred to as the extraction energy of the ion beam, is determined by the potential difference between the ion source 15 and the flight tube, which
20 is controlled by the flight tube voltage supply 75. Thus, for example, to transport the ion beam at an energy of 10 keV through the flight tube, the flight tube is biased at -10 kV relative to the ion source or -8 kV relative to ground. The ion beam is transported
25 with substantially constant energy through the analysing magnet and different ionic species within the ion beam are resolved spatially by the magnet according to their mass. The spatially resolved beam then passes into the mass resolving chamber, where the
30 beam first passes through a predefining aperture defined by the plate electrode 35 closest to the analysing magnet 5. The plate electrode 35 acts as a course, first stage filter for the spatially resolved

beam and blocks a proportion of the spatially resolved
ion species which are not required in the implant.
The second and third elements 39 and 41 spaced from
the analysing magnet 5, and which are displaced

5   axially from one another along the beamline, define a
variable width mass resolving slit 42, whose position
can be varied in a direction transverse to the
beamline, for selecting from the filtered beam the ion
species to be implanted.

10   As an example, in a boron implant the spatially
resolved beam leaving the analysing magnet may contain
BF_3, BF_2, BF, B and F ions and the molecular and boron
ions will contain either isotope of boron, B_{10} and B_{11}.
Thus, for a boron-11 implant the predefining element

15   35 and the mass resolving elements 39, 41 will filter
out all ionic species except B_{11}.

     As the beam traverses the mass resolving chamber
47, the energy of the beam is maintained constant, in
this example 10 keV. The 10 keV mass resolved beam 46

20   passes through the exit aperture 55 of the mass
resolving chamber 47, through the screening assembly
52 to the electrode assembly 9.

     A potential is applied to the field electrode 61
of magnitude less than that of the mass resolving

25   chamber 47. The magnitude of the potential applied to
the field electrode 61 is sufficient to establish an
electrostatic focusing field in the region of the
final aperture 67 of the grounded plate electrode 65.
The inventors have found that a potential of between

30   -5 kV and -30 kV and preferably -25 kV with respect to
the potential of the plate electrode 65 is sufficient
to establish the required focusing field at the final
lens aperture 67 to maintain the beam ions within the

beam between the final lens aperture 67 and the target substrate. As the flight tube and the mass resolving chamber are at -8 kV, the field electrode 61 is biased to a potential lower than the potential of the flight

5   tube and serves to prevent electrons in the mass resolving region from being drawn to the plate electrode 65, which would destroy space charge neutralisation in this region and cause beam expansion and loss of current.

10   In the present example, as the mass resolved beam 46 approaches the field electrode 61, the beam is briefly accelerated above the transport (extraction) energy of 10 keV to an energy defined substantially by the potential difference between the ion source 15 and

15   the field electrode 61. The beam passes through the field electrode aperture 63 and is then decelerated to substantially the required implant energy in the gap between the field electrode aperture 63 and the final aperture 67. At the same time, a net focusing force

20   is applied to the ion beam in the region between the mass resolving chamber exit aperture 55 and the field electrode 61, and in the region between the field electrode 61 and the plate electrode 65 of the deceleration lens and just beyond.

25   The ion beam then passes into the region between the final lens aperture 67 and the target substrate. In this region, the ion beam is transported to the substrate at substantially the required implant energy. Expansion of the now, low velocity beam is

30   minimised by flooding the beam with low energy electrons by means of the plasma flood system 13. The plasma flood system also minimises surface charging of the target substrate during ion implantation and

simultaneously reduces the potential of the ion beam, again to minimise the extent to which the beam expands before reaching the substrate.

The retardation apparatus of the present invention represents a significant advance over prior art systems. Firstly, the present retardation apparatus allows the ion beam to be neutralised after the beam has been decelerated, which is not possible in the prior art systems. The difficulty of space charge neutralising the ion beam at the target by using some system of introducing electrons into the beam arises because, as ions are being decelerated in a retardation field, the retardation field accelerates electrons away from the beam ions, so that the electron injector is substantially ineffective. In the case of a plasma flood system, in which the ion beam is neutralised by low energy electrons contained in a stable plasma, the intense electric fields present in a retardation lens would prevent such a plasma from being formed. In the present arrangement, the plasma flood system is arranged downstream of and is screened from the retardation apparatus, so that the plasma flood system is not exposed to the intense retardation fields. This allows the critical conditions for forming the required low energy plasma to be established and maintained.

Secondly, loss of space charge neutralisation is inevitable as the ion beam travels through the intense retardation field. Accordingly, in the prior art arrangements, the retardation lens is placed as close to the target as possible so that the beam travels a minimum distance without space charge neutralisation. In contrast, in the present arrangement, the

retardation apparatus is set back upstream from the
target substrate, between the neutralising apparatus
and mass resolving chamber, and is arranged to apply a
focusing force to the ion beam during retardation to
5   oppose beam expansion in this region where space
charge neutralisation of the ion beam is considerably
depleted. It has been found that by making the final
lens aperture 67 of the retardation electrode 65 at
least 15% larger than the beam cross-sectional area at
10   the final aperture, and applying a sufficiently high
potential difference between the field electrode 61
and the plate electrode 65 in a direction which
decelerates the ion beam in the region between these
electrodes, surprisingly high current densities can be
15   achieved at the target substrate. For example, on-
target ion current densities of 70 and 250 μAcm^{-2} have
been achieved for low energy beams of 2 keV and 10
keV, respectively, and on-target ion current densities
of 5.0 and 20.0 μAcm^{-2} have been achieved for ultra-
20   low energy (< 1 keV) beams of 200 eV and 500 eV,
respectively.

The aperture 63 of the field electrode 61 is also
larger than the beam cross-sectional area thereat and
is capable of transmitting all the beam current. In
25   this embodiment, the aperture size is substantially
constant along the beamline and the depth of the
aperture in the direction of the beamline is
relatively small.

The aperture 64 of the field defining electrode
30   56 and the exit aperture 55 of the mass resolving
chamber are also sized larger than the beam cross-
sectional area thereat, so that all the beam current
transmitted by the mass resolving slit 42 and the beam

height defining aperture 44 enters the retardation
zone. Thus, beyond the beam height defining aperture
44, all the apertures through which the beam passes to
the substrate are larger than the beam cross-section
5   at a respective aperture so that all the beam current
from the beam height defining element 43 can be
transmitted to the substrate. This is a significant
departure from prior art arrangements, in which the
size of apertures along the beamline are restricted in
10   order, for example, to define the width and shape of
the beam at the target, to provide an impedance to gas
flow through the aperture so that a differential
pressure across the aperture can be maintained or to
enable the inner face of the aperture to be as close
15   to the ion beam as possible so that a lower potential
can be applied to the electrodes.

We define the ratio of the cross-sectional area
of the beam at a given aperture to the area of the
aperture as the 'filling factor'. It is preferred
20   that the filling factor of the focusing electrode 61
and the lens plate electrode 65 is less than 85% for
all species of dopant ions. It has been found that
filling factors of less than about 85% allow higher
beam current densities to be transported along the
25   beamline. It is believed that providing a reasonable
gap between the beam and the various beamline
electrodes reduces beam expansion due to space charge
effects, since the electric field generated by an
electrode transverse to the beamline causes less
30   disturbance to the ions and electrons transported at
the periphery of the ion beam than if the inner face
of the electrode aperture is close to the ion beam.
Thus, by ensuring that the size of the apertures of

the electrodes downstream of the mass resolving slit are all larger than the beam cross-section thereat, beam expansion can be reduced and the beam current density increased. Furthermore, sizing the apertures

5 larger than the beam cross-section prevents the beam ions from striking the electrodes, thereby substantially reducing contamination of the beam by graphite, metallic or other materials which would otherwise be sputtered from the surface of the

10 electrodes.

The inventors have found that there can be problems with energy contamination of the decelerated low energy ion beam at energies above the transport energy and that such contamination results from

15 neutralisation of the beam ions as they are temporarily accelerated by the field electrode before being decelerated in the region between the field electrode and lens plate electrode.

Figure 2 shows a plan view of a preferred

20 embodiment of a beam transport apparatus for low energy ion implantation which substantially eliminates such high energy contamination of the ion beam. In Figure 2, the ion beam generator, most of the mass analysing magnet and the beam stop of the ion

25 implanter have been omitted for clarity, but these may be the same as those described above and shown in Figure 1. Referring to Figure 2, the apparatus comprises a flight tube 27 including a mass resolving chamber 47 housing an ion selector 7 for selecting the

30 desired implant ions from the mass analysed beam from the magnet 5, a deceleration lens assembly 9 downstream of the mass resolving chamber 47 for decelerating the ion beam, a beam neutralising

apparatus downstream of and adjacent to the deceleration lens assembly, and a target substrate holder 11 downstream of and adjacent to the beam neutralising apparatus 13.

5   The ion selector 7 comprises a plate electrode 35 which rejects most of the unwanted ion species from the magnet and a pair of elements 39,41, which together defines a variable width mass resolving slit 42 which passes only the selected ion specie. The
10   mass resolving chamber wall 49 comprises a part 51 which extends in the direction of the beam line and defines a generally cylindrical envelope, and a front end portion 53 which constitutes a plate electrode extending transverse to the beam line. The front end
15   portion 53 defines an aperture 55 through which the ion beam can pass and which is adjacent the mass resolving slit defining elements 39 and 41.

Referring to Figures 2 to 5, the deceleration lens assembly comprises a first apertured plate
20   electrode 65 for controlling the implant energy and positioned adjacent the beam neutralising apparatus 13, a second apertured plate electrode 60 located upstream of the first apertured electrode 65, and a field electrode 61 located between and adjacent to the
25   first and second apertured plate electrodes 65,60 for providing a focusing field for beam ions passing through the first apertured plate electrode 65. An additional apertured plate electrode 56 is located upstream of the second apertured plate electrode 60 to
30   provide further screening of the ion selector 7 from electric fields generated downstream of the ion selector 7 and in particular from fields originating at the field electrode 61. In this particular

embodiment, the additional screening electrode 56 is mounted on stand-offs 66 extending rearwardly from the second apertured electrode 60.

A screening cylinder 54 is mounted on the flight tube 27 and extends axially towards the field electrode 61. The second apertured plate electrode 60 is mounted on the forward end of the screening cylinder 54 and the screening cylinder 54 encloses the additional screening electrode 56. In this embodiment, the screening cylinder 54, the second apertured plate electrode 60 and the additional apertured plate electrode 56 are all electrically connected to the flight tube 27.

Returning to the deceleration lens assembly, the beam apertures formed in both the field electrode 61 and the first apertured electrode 65 are rectangular and in each case the width w_f and w_d of the aperture is shorter than the height h_f and h_d. The aperture formed in the first apertured electrode 65 is smaller than that of the field electrode 61 in both height and width to provide enhanced screening of the beam neutralising apparatus 13 from the electric field originating at the field electrode 61. In one embodiment, the beam aperture 63 of the field electrode has dimensions of about 86 x 100 mm and the beam aperture 67 of the first apertured plate electrode has dimensions of about 60 x 86 mm.

The fractional reduction in the aperture width between the field electrode and first apertured plate electrode 65 is greater than the fractional reduction in aperture height between the field and first apertured electrode. In this embodiment, as the ion beam passes through the mass resolving slit, the beam

has a pencil-like cross-sectional geometry so that the beam tends to expand laterally at a faster rate than it does vertically due to space charge effects. The larger reduction between the widths of the apertures

5 intensifies the focusing force in the lateral direction across the width of the ion beam to counteract the higher expansion rate in this direction. The beam aperture configuration of the first apertured plate electrode 65 and the field

10 electrode 61 increases the focusing capacity of the deceleration lens so that the potential of the field electrode relative to the first and second apertured electrodes necessary to provide adequate focusing of the beam can be reduced, thereby reducing the energy

15 briefly attained by the ion beam above the transport energy on passing through the field electrode aperture. This in turn reduces the energy of fast neutrals created in this region by charge exchange with residual gas atoms.

20 Referring to Figure 2, the first and second apertured plate electrodes 65 and 60 are spaced apart in the beam direction by a distance 'a' of less than the smallest transverse dimension 'w_f' (in this case the width) of the beam aperture of the field electrode

25 61. This is another important feature of the preferred deceleration lens assembly. The short distance between the first and second apertured plate electrodes 65,60 ensures that the time that ions have an energy above the transport energy as they are

30 accelerated by the field electrode 61 is kept to a minimum. Consequently, the probability of beam ions at these higher energies experiencing charge exchange collisions with residual gas atoms is reduced with a

concomitant reduction in the number of high energy neutrals formed in this region.

The field electrode 61 is generally cylindrical and has an axial length in the beam direction of at least 10% of the smallest transverse dimension of the beam aperture (in this case the aperture width). In this particular embodiment, the axial length is about 23% of the aperture width. This configuration enhances the focusing effect whilst permitting the aperture of the field electrode 61 to be larger than the expanded beam width as it passes through the field electrode.

A cylindrical flange 89 extends axially from the first apertured plate electrode 65 towards the field electrode 61. The cylindrical flange 89 and the first apertured plate electrode 65 form a shield around the ion beam and the field electrode 61, to confine the electric field established by the potential difference applied between the field electrode 61 and the first apertured plate electrode 65, thereby preventing charged particles near the target substrate 12 from flowing upstream to the field electrode 61, and at the same time screening the ion beam from any stray electric fields present in the process chamber 81, which might otherwise upset the charge balance in the ion beam causing loss of beam current.

The field electrode 61 is located inside the flange 89 so that the flange surrounds the outer periphery of the field electrode 61. In this embodiment, the field electrode 61 is mounted in and supported by the cylindrical screening flange 89 via a plurality of stand-offs 68 which are positioned radially around the periphery of the field electrode

61. The field electrode and first apertured plate
electrode assembly is mounted on the process chamber
wall 85 by a plurality of stand-offs 72. In this
embodiment, the cylindrical screening flange 89

5   extends a minimal distance beyond the rearward face of
the field electrode 61 so that the gap 95 between the
field electrode and the second apertured plate
electrode is easily accessible and communicates
directly with the surrounding space within the process

10   chamber 81. This open geometry enables the region
between the field electrode 61 and the second
apertured plate electrode 60 to be evacuated more
easily so that the residual gas pressure in this
region can be reduced to minimise the production of

15   fast neutrals which would otherwise cause high energy
contamination.

A vacuum port 83 is formed in the wall of the
process chamber 81 to allow the process chamber to be
evacuated. The opening of the vacuum port is

20   relatively large and extends paralel to the beam line
in the region of the target substrate to collect
particles sputtered from the target during
implantation. The deceleration lens assembly, in
particular the region between the field electrode 61

25   and the second apertured plate electrode 60, is
located directly in front of the vacuum outlet port 83
of the process chamber 81 so that the interior of the
lens can be evacuated more efficiently, which assists
further in minimising the production of fast neutrals

30   and high energy contamination of the ion beam.

Thus, the deceleration lens assembly shown in
Figure 2 is configured and constructed so as to allow
the space within the lens to be evacuated effectively

so as to minimise the residual gas pressure in the interior of the lens and the production of neutrals in this region above the implant energy and in particular above the flight tube transport energy.

5   In this embodiment, the beam neutralising apparatus 13 comprises a plasma flood system comprising a plasma source 14 which injects electrons into the ion beam near the surface of the target substrate. The plasma flood system includes an

10   electron confinement tube 69 which surrounds the ion beam and is located immediately in front of the target holder 11. A screening electrode 70 for screening the plasma flood system from electric fields originating at the deceleration lens assembly is mounted on the

15   upstream end of the confinement tube 69 and is located adjacent the first apertured plate electrode 65. This construction permits the lens assembly 9 to be located as closely as possible to the target substrate 12 while still permitting the neutralisation apparatus 13

20   to be located between the two. The additional screening electrode 70 has a beam aperture 74 of approximately the same size as the beam aperture 67 in the first apertured plate electrode 65 and substantially prevents extraneous electric fields from

25   penetrating into the neutralisation region. The additional screening electrode 70 permits the first apertured electrode 65 to be located very close to the upstream end of the electron confinement tube 69 and for the confinement tube 69 itself to be made

30   relatively short whilst still providing adequate neutralisation of the substrate 12 being implanted.

        Figure 2 also shows an example of how the beam width profile changes along the beam line as the beam

passes from the analysing magnet 5 through the
deceleration lens assembly to the target substrate 12.
The magnet optics bring the ion beam to a narrow focus
at the mass resolving slit 42 defined by the mass

5   resolving elements 39,41. As the ion beam passes
through the mass resolving slit 42, and through the
beam apertures 55 and 58 of the mass resolving chamber
47 and additional screening plate electrode 56, the
beam width gradually expands. As the beam approaches

10   the beam aperture 62 of the second apertured plate
electrode 60, the electric field between the field
electrode 61 and the second apertured plate electrode
60 initially applies a focusing force to the ion beam
which reduces the rate of expansion and subsequently

15   applies a defocusing force to the ion beam, as the
beam approaches the field electrode 61 and is briefly
accelerated above the transport energy. However, the
electric field between the field electrode 61 and the
second apertured plate electrode 60 applies a net

20   focusing force since the ion beam has a lower velocity
and therefore spends more time experiencing the
focusing force in the region nearer the beam aperture
of the second apertured plate electrode 60.

As the ion beam passes through the field

25   electrode 61 into the gap between the field electrode
61 and the first apertured plate electrode 65, the
beam is decelerated to the desired implant energy and
the electric field between these electrodes applies a
strong focusing force to the ion beam so that the beam

30   width narrows to pass through the beam aperture 67 of
the first apertured plate electrode 65.

Finally, the ion beam passes into the electron
confinement tube 69 of the neutralising apparatus 13

via the beam aperture 74 of the screening plate electrode 70 to the target with negligible divergence of the beam width.

Another important aspect of the present invention 5 is that the ion implanter is arranged so that the path length between the mass analysing magnet and the retardation apparatus can be made much shorter than prior art implanters. As mentioned above, this not only allows the implanter to be more compact, but also 10 reduces the production of fast neutrals which cause energy contamination of a low energy ion beam. Essentially, fast neutrals which could impinge upon the target are produced anywhere upstream of the retardation electrode having a direct line of sight to 15 the target. Neutrals which are produced in the region between the first apertured plate electrode of the deceleration lens and the target will have an energy equivalent to or less than the implant energy and therefore will not cause high energy contamination. 20 To shorten the critical path length in which fast neutrals could be formed, the flight tube downstream of the analysing magnet is made as short as possible by including only a mass resolving assembly between the magnet and the deceleration lens assembly. The 25 unique deceleration lens assembly allows the distance between the first apertured plate electrode and the end of the mass resolving assembly to be as short as possible by virtue of its extremely simple construction. In the embodiments shown in Figures 1 30 and 2, the first apertured plate electrode 65 which controls the final energy of the ion beam is placed as close as possible to the exit aperture 55 of the mass resolving chamber 47. The deceleration apparatus

comprises only one further electrode, namely the field electrode 61, placed between the first apertured plate electrode 65 and the end 53 of the mass resolving chamber 47 to control the shape of the beam in the

5   retardation region and through the final aperture 67 of the lens assembly to achieve substantially 100% transmission of the beam current to the target substrate, given that the apertures of both the field electrode 61 and the final aperture 67 are both larger

10   than the beam cross-section thereat.

        It has been found necessary to include a finite gap between the field electrode 61 and the end 53 of the mass resolving chamber 47 in which to incorporate some screening means extending along the beamline, in

15   order to reduce penetration of the electric field from the focusing electrode 61 through the mass resolving chamber exit aperture 55 to an acceptable level. Essentially, it is not possible to provide sufficient screening by reducing the size of the exit aperture 55

20   alone without the edge of exit aperture 55 clipping the beam. Sufficient screening of the electric field without beam clipping can only be obtained by including a shield around the ion beam which extends over a finite length of the beamline between the field

25   electrode 61 and the end of the mass resolving chamber. In the embodiments shown in Figures 1 and 2, the screening means comprises a hollow cylindrical electrode 54 which is effectively an extension of the flight tube and an additional apertured plate

30   electrode 56. For a given size of mass resolving chamber exit aperture 55, the screening length is preferably made as short as possible. It has been found that the screen length provided by a cylindrical

shield alone can be shortened considerably by placing an additional apertured plate electrode 56 between the field electrode 61 and the front end 53 of the mass resolving chamber. Reducing the screening length not only contributes to the shortening of the overall beam path length between the magnet and the first apertured plate electrode of the deceleration lens, but also minimises the distance over which ions are momentarily accelerated to energies above the extraction energy, thereby mitigating energy contamination in this critical region.

Another advantage of reducing the path length of the ion beam between the magnet and the first apertured plate electrode of the deceleration lens assembly is that at the first apertured plate electrode, the beam width due to space charge expansion will be less than for a longer path length. In other words, for a shorter path length, a larger beam expansion can be tolerated. This feature gives rise to a significant benefit in enabling the ion beam to be transported at a lower energy, so that the difference between the implant energy and the transport energy can be reduced. Thus, the ion implanter can be controlled so that any neutrals generated upstream of the first apertured plate electrode have energies only slightly greater than the implantation energy and therefore only penetrate into the target substrate slightly deeper than the implant ions. Furthermore, reducing the beam path length between the ion beam generator and the target substrate decreases the number of neutralisation interactions, so that less ion current is lost in creating neutrals. In the embodiments shown in

Figures 1 and 2, the length of the implanter from the
magnet to the end of the process chamber is about 2 m,
the distance between the magnet exit aperture 31 and
the target substrate 12 is approximately 90 cm, and

5   the distance between the magnet exit aperture 31 and
the first apertured plate electrode 65 is
approximately 60 cm. High energy neutrals which could
cause energy contamination of the ion beam at the
substrate may also be formed in the region upstream of

10   the exit aperture 31 of the analysing magnet 5.
Advantageously, the length of this region having a
direct line of sight to the substrate, may be
shortened by increasing the magnetic field strength of
the analysing magnet to bend the ion beam into a

15   tighter arc. The compact beamline arrangement,
including the retardation apparatus, between the
analysing magnet and the target substrate enables the
magnet arc radius to be substantially decreased, and
in the embodiments shown in Figures 1 and 2, the

20   radius is 23 cm. Advantageously, this allows the
whole of the beam path length from the ion beam
generator to the substrate to be shortened, thereby
further decreasing the size of beam cross-section at
the substrate and reducing loss of beam current from

25   the ion beam generator to the target.
The ion implanter may also be used such that the
final implant energy is greater than the energy at
which the beam is transported through the analysing
magnet (referred to as acceleration mode). In this

30   case, with reference to Figure 1 or 2, the ion beam is
transported at a predetermined energy through the mass
analysing magnet 5 and the mass resolving chamber 47,
and is then accelerated to the final implant energy

using the electrode assembly 9. For example, for an
implant energy of 80 keV, the ion source potential is
set at 80 kV with respect to the first apertured plate
electrode 65 and target substrate 11, which are both
5   at ground. The extraction electrode 23, the flight
tube and screening apparatus up to and including the
second apertured plate electrode 60 are all set to a
potential relative to the potential of the ion source
which determines the transport energy of the ion beam
10   along the flight tube. For example, for an extraction
energy of 30 keV, the potential of the flight tube
relative to ground is set at +50 kV. As for the case
where the implant energy is lower than the extraction
energy (referred to as decel or retardation mode), the
15   field electrode 61 is again biassed at a potential
lower than the first apertured plate electrode 65 in
order to establish a gentle focusing field in the
region of the final aperture 67 of the lens assembly,
to concentrate the ion beam in this region. For
20   example, the field electrode 61 may be biassed at -25
kV relative to the first apertured plate electrode.
As the ion beam passes through the mass resolving
chamber exit aperture 55, the beam is firstly
accelerated by the field between the field electrode
25   61 and the end 53 of the mass resolving chamber 47, to
an energy greater than the implant energy and is then
decelerated in the region between the cylindrical
electrode 61 and the plate electrode 65 to the final
implant energy of .80 keV. It has been found that both
30   high and low energy beams can be successfully
transmitted to the substrate by operating the ion
implanter in accel and decel mode respectively,
without substantially changing potential difference

applied between the first apertured plate electrode 65
and the cylindrical electrode 61. Thus,
advantageously, once the potential difference between
these electrodes is set, no further adjustment of the
5   potential difference is required, which simplifies
switching between low energy and high energy implants.

In order to transport a beam of ions
successfully, the pressure of the gas through which
the beam passes must be high enough to supply a
10   sufficient number of electrons to neutralise the beam.
The electrons are generated as the ion beam interacts
with the residual gas atoms and are trapped in the
potential well formed by the electrostatic charge of
the positive ions. A gas pressure of between 10^{-3} and
15   10^{-2} Pa (10-5 - 10^{-4} mbar) is commonly used in most
commercial ion implanters. However, the present
retardation electrode arrangement allows the residual
gas pressure within the retardation region to be
pumped to lower pressures, as the apertures formed in
20   both the first apertured plate and field electrodes
can be substantially larger than the beam cross-
section. Thus, gas within the retardation region can
be pumped through the apertures at a higher rate,
resulting in a lower gas pressure in this region.
25   Furthermore, as the field electrode is the only other
electrode required in addition to the first apertured
plate electrode to decelerate and transmit the ion
beam to a remote target, the electrode assembly is
extremely simple and can easily be configured as an
30   open structure which may be efficiently evacuated.
The advantage of reducing the residual gas pressure in
the retardation zone is that the number of
interactions between beam ions and residual gas atoms

is reduced, so that less ion current is lost and fewer neutrals are produced resulting in less energy contamination of the ion beam. It has been found that the residual gas pressure can be decreased by about an order of magnitude or more, i.e., to at least 10^{-6} mbar, without a significant increase in the rate of beam divergence. However, a decrease in pressure of at least an order of magnitude does result in a corresponding decrease of at least an order of magnitude of energy contamination. Advantageously, the focusing action of the retardation apparatus tends to compensate for any increase in the rate of beam divergence in this region, so allowing the gas pressure to be reduced.

Referring again to Figure 2, the deceleration lens assembly 9, the plasma flood system 13 and the target substrate support 11 are all housed within a process chamber 81 which is positioned adjacent the mass resolving chamber 47 and communicates with the mass resolving chamber through an aperture 55 formed in the front end section 53 of the mass resolving chamber. The screening cylinder 52 between the front end wall 53 of the mass resolving chamber 47 and the second apertured plate electrode 60 screens the ion beam from stray electric fields in the process chamber 81 and is perforated so that this part of the beam line can be efficiently evacuated. A vacuum outlet port 83 is formed in the wall 85 of the process chamber 81 and is connected to a vacuum pump 86 (shown in Figure 1). The vacuum pump is preferably a cryogenic pump capable of pumping at a rate of about 10,000 litres per second. The mass resolving chamber wall 49 is electrically insulated from the process

chamber wall by an electrically insulating member 87 which forms part of the wall of the process chamber 81.

The mass resolving chamber 47, constitutes part of the critical path length between the analysing magnet 5 and the first apertured plate electrode 65 in which fast neutrals can be generated which may cause energy contamination of the ion beam. Although a finite residual gas pressure is required within the mass resolving chamber to provide space charge neutralisation of the ion beam, there is a substantial range of pressures over which the ion beam is sufficiently well neutralised to allow the pressure to be reduced to decrease the number of fast neutrals generated in this region. An important advantage in making the critical path length as short as possible is that a higher rate of expansion of the ion beam can be tolerated so that good space charge neutralisation is less important. An aspect of the present invention exploits this higher tolerance of beam expansion created by the shortened critical path length by reducing the pressure in the mass resolving chamber. Although a vacuum outlet port 57 is formed in the wall 49 of the mass resolving chamber 47 and is connected to a vacuum pump 59 (shown in Figure 1), the size of the outlet port 57 and therefore the throughput is limited by the length of the mass resolving chamber, which ideally should be as short as possible. Although the mass resolving chamber communicates with the process chamber 81 through the exit aperture 55 formed in the end part 53, so that, at least to some extent, the mass resolving chamber can be evacuated through this aperture via the process chamber 81, the

size of this aperture is limited as it must not allow significant penetration of the electric field originating at the field electrode 61 into the mass resolving chamber 47. To enable the pressure within
5   the mass resolving chamber 47 to be substantially reduced below that which was previously possible, a plurality of further apertures 103 are formed in the dividing wall 51 between the mass resolving chamber 47 and the process chamber 81 to provide additional
10 outlets through which the mass resolving chamber can be evacuated through the process chamber vacuum port(s) 83 by the process chamber vacuum pump(s) 86. In this embodiment, the apertures are formed in the part of the mass resolving chamber wall which extends
15 generally in the direction of the beam line, although in other embodiments the further apertures may be formed in ohter parts of the wall, including those which extend transverse of the beam line. The size and spacing of the apertures is carefully chosen to
20 preserve the screening of the ion beam provided by the dividing wall 51 and so that the ion beam is not disturbed by the discontinuity of the equipotential surface at the dividing wall, which could cause loss of beam current. In one embodiment, the apertures are
25 formed as elongate slots, but may be square, rectangular, circular or rhombic or any other suitable shape.

The combination of the relatively large apertures of the deceleration lens assembly and the further
30 apertures formed between the mass resolving chamber and the process chamber enable the critical beam path length between the analysing magnet and the retardation electrode 65 to be pumped to much lower

pressures than has been previously possible, and advantageously, this has been achieved without additional vacuum pumps or increasing the length of the mass resolving chamber to accommodate a larger

5   vacuum port. In fact, the additional outlet apertures between the mass resolving chamber 47 and the process chamber 81 may provide a throughput such that a separate mass resolving chamber vacuum pump is not required, simplifying the implanter and saving cost.

10   Furthermore, the short beam path length allows the total volume which is to be evacuated to be substantially reduced.

One embodiment of the present invention includes a wafer support assembly comprising a plurality of

15   individual support plates supported by and positioned around a rotatable hub via a plurality of radially extending spokes. Figure 2 shows one such support plate 107 connected to a spoke 109, with the support plate 107 supporting a target substrate, for example a

20   semiconductor wafer 12. The wafer support assembly can be moved in a direction transverse to the beamline so that the wafer can be scanned across the beam.

A further significant advantage of the present arrangement is that the focusing action of the

25   retardation apparatus can be used to decrease the processing time of a single wafer, thereby increasing the wafer throughput of the ion implanter. For a low energy ion beam, i.e., typically below 10 keV, the beam width at the target substrate can be reduced to

30   below that of a high energy beam, e.g., 20 keV, since there is no longer a requirement to use relatively wide beams to avoid energy density problems such as excessive charging and heating of the target wafer.

The focusing action of the retardation apparatus can be used to reduce the on-target beam width which allows a reduction in the distance through which the spinning wafer support assembly must be scanned so that the wafers are uniformly doped by the ion beam. This enables the processing time for a given batch of wafers to be decreased so increasing the throughput of the implant machine.

In other embodiments of the ion implanter, any one or more of the apertured plate and field electrodes or screening electrodes in the process chamber may have at least one further aperture formed therein to provide additional outlets through which any enclosed volume can be pumped to achieve even lower pressures. The electrode may include an array of such apertures and may comprise a mesh. The dividing wall between the mass resolving chamber and the process chamber may also comprise a mesh, to enable even lower pressures within the mass resolving chamber to be achieved. Importantly, the mesh should be sized to provide adequate screening of the ion beam.

In other embodiments, the first apertured plate or electrode and the focusing or field electrode may have any suitable shape and configuration and each may comprise one or more individual electrodes. For example, the retardation electrode may include a cylindrical or ring electrode. In another embodiment, the retardation electrode and the plasma flood guide tube may comprise a single electrode or be electrically connected together. In another embodiment, the retardation electrode may be arranged so that it can be biassed to a potential different

from that of the target substrate.

In another embodiment, the focusing or field electrode may comprise an extension of the flight tube and be substantially at the flight tube potential. In this embodiment, the potential difference between the flight tube and the first apertured plate or retardation electrode should be sufficient to apply a focusing force to the ion beam in the retardation zone. An additional electrode upstream of the retardation electrode and within the flight tube and biassed at a potential lower than that of the flight tube should be provided to prevent electrons being lost to the retardation electrode.

Modifications to the embodiments described above will be apparent to those skilled in the art.

CLAIMS

1.   An ion implanter for implanting ions into a
substrate, comprising an ion beam generator for
5   producing a beam of ions, a flight tube to transport
said beam at a transport energy, a substrate holder
for holding a substrate to be implanted with beam
ions, a deceleration potential generator connected to
apply a deceleration potential between the flight tube
10   and the substrate holder to decelerate beam ions to a
desired implant energy, a deceleration lens assembly
located between the flight tube and the substrate
holder and comprising a first apertured plate
electrode connected to be substantially at the
15   substrate potential, and a field electrode located
adjacent and upstream in the beam direction relative
to said first electrode, a potential bias supply
connected to bias said field electrode relative to
said first electrode, said electrodes being arranged
20   and said bias being such as to provide a focusing
field for beam ions passing through said first
electrode, said deceleration lens assembly further
including a second apertured plate electrode connected
to be substantially at the flight tube potential and
25   located adjacent and upstream in the beam direction
relative to said field electrode, mass selection
apparatus in the flight tube to select a desired mass
of ions for transmission in the ion beam from the
flight tube, said mass selection apparatus including
30   an electromagnetic screen at the flight tube potential
to screen the mass selection apparatus from electric
fields generated downstream in the beam direction,
said screen providing an exit aperture for said mass

selected ion beam from the flight tube, and at least
one additional mass selection apparatus screening
electrode comprising an apertured plate at the flight
tube potential located between said second electrode

5   and said exit aperture.

2.   An ion implanter as claimed in Claim 1 and
including a screening cylinder mounted on the flight
tube at the flight tube potential and extending

10   axially towards said field electrode to contain the
ion beam, said second apertured plate electrode being
mounted on the end of the screening cylinder adjacent
to the field electrode and said screening cylinder
being perforated to assist evacuation of the interior

15   of the cylinder.

3.   An ion implanter as claimed in Claim 2, wherein
the apertured plate forming said additional screening
electrode is located in said screening cylinder.

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4.   An ion implanter as claimed in any preceding
claim and including neutralisation apparatus located
between the substrate holder and said first electrode
to provide a supply of low energy charged species of

25   opposite polarity to the beam ions for neutralising
surface charge build-up on the substrate during
implantation.

5.   An ion implanter as claimed in Claim 4 and

30   including a neutralisation apparatus screen electrode
comprising an apertured plate located between said
first electrode and said neutralisation apparatus.

6.　An ion implanter as claimed in either of Claims 4 or 5, wherein said first apertured plate electrode has a cylindrical screening flange extending axially from the first electrode towards said field electrode and 5　the field electrode is mounted inside the flange so that the flange surrounds the outer periphery of the field electrode.

7.　An ion implanter as claimed in any preceding 10　claim and including a process chamber containing said substrate holder and having an outlet port, and a vacuum pump connected to said outlet port for evacuating the process chamber, wherein said deceleration lens assembly is located directly in 15　front of said outlet port to the vacuum pump.

8.　An ion implanter as claimed in any preceding claim and including a beam defining aperture located between said field electrode and said ion beam 20　generator which is effective to define the width of the beam in at least one direction normal to the beam direction as the beam passes through the field electrode and said first electrode, wherein said field electrode has an aperture larger in said one direction 25　than the width of the beam in said one direction as the beam passes through said field electrode and said first electrode has an aperture which is sufficiently larger in said one direction than the width of the beam in said one direction as the beam passes through 30　said first electrode that beam ions avoid high radial field components at the periphery of the aperture of the first electrode which would tend to deflect ions out of the beam.

9.   An ion implanter as claimed in any preceding
claim wherein for at least one direction normal to the
beam direction the beam aperture of the first
electrode is smaller than the beam aperture of said
5   field electrode.

10.   An ion implanter as claimed in any preceding
claim wherein said potential bias supply is arranged
to provide a bias such that said field electrode is at
10   a negative potential of more than 5 kV relative to the
flight tube.

11.   An ion implanter as claimed in any preceding
claim wherein said field electrode is cylindrical with
15   its axis in the beam direction and has a length at
least 10% of the smallest transverse dimension of the
cylinder.

12.   An ion implanter as claimed in any preceding
20   claim and including a magnet for resolving spatially
the beam ions according to their mass, a process
chamber containing said substrate holder and having an
outlet port, a first vacuum pump connected to said
outlet port for evacuating the process chamber, a mass
25   selection chamber between said process chamber and
said magnet, a second vacuum pump connected to
evacuate said mass selection chamber, an aperture for
the beam to pass from the mass selection chamber to
the process chamber and at least one further aperture
30   between said mass selection chamber and said process
chamber to improve evacuation of one or the other of
said chambers.

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Claims searched:	all	Date of search:	30 March 2000

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

    UK Cl (Ed.R): H1D (DHAC,DHC,DHX)

      Int Cl (Ed.7): H01J (37/02,37/09,37/30,37/317)

Other: Online: EPODOC,WPI,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0473097 A	(Nissin Electric) see fig 1A and page 9, lines 2-13	
A	EP 0451907 A	(Philips) see e.g. fig 1b	
A	US 4929839 A	(Microbeam) see e.g. col 6, lines 20-24 and 57-62	
A	US 4782304 A	(Applied Materials) see fig 13	

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